Using textual analysis with Concept Inventories to identify root causes of misconceptions

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Abstract— **Engineers must have deep and accurate conceptual understanding of their field and Concept inventories (CIs) are one method of assessing conceptual understanding and providing formative feedback. Current CI tests use Multiple Choice Questions (MCQ) to identify misconceptions and have undergone reliability and validity testing to assess conceptual understanding. However, they do not readily provide the diagnostic information about students' reasoning and therefore do not effectively point to specific actions that can be taken to improve student learning. We piloted the textual component of our diagnostic CI on electrical engineering students using items from the signals and systems CI. We then analysed the textual responses using automated lexical analysis software to test the effectiveness of these types of software and interviewed the students regarding their experience using the textual component. Results from the automated text analysis revealed that students held both incorrect and correct ideas for certain conceptual areas and provided indications of student misconceptions. User feedback also revealed that the inclusion of the textual component is helpful to students in assessing and reflecting on their own understanding.**

Keywords—Concept inventories; telecommunications engineering; formative assessment; conceptual understanding

I. Introduction

Conceptual understanding of fundamental STEM ideas is critical to developing students' ability to solve problems and apply knowledge in different contexts [1,2]. A major challenge for assessing students' conceptual understanding of STEM subjects is the capacity of assessment tools to reliably and robustly evaluate student thinking and reasoning. Concept inventory (CI) testing is one method to evaluate conceptual understanding through multiple-choice questioning, however it doesn't provide measures of higher-level thinking.

Current concept inventories have been developed and validated to assess student misconceptions based students' selection of distractor questions. The drawback to concept inventories and multiple-choice testing is that it lacks the capacity to assess fully accurate understanding of concepts. Previous studies on conceptual understanding in STEM subjects showed constructed response measures, or short-answer questioning, revealed that students held both correct and incorrect ideas, which went undetected by multiple choice testing [3].

Engineering students' low conceptual understanding of fundamental engineering concepts is due to misconceptions that limit or prevent conceptual change [1]. The study described in this work in progress builds on measurement-focused research regarding conceptual change, i.e. concept inventories, and explores how textual analysis can further change and improve conceptual understanding.

We are in the process of developing an assessment tool that incorporates a textual component to capture explanations of students' multiple-choice selections. Our tool incorporates constructed response measures (written explanations) with a subset of the multiple-choice Signals and Systems CI [4]. The development of this tool ultimately aims to improve usability of an online CI interface, test textual analysis approaches for large classes, and provide a foundation for the application of text-enriched CIs.

In this paper, we describe the design of a pilot investigation, leading to the creation of a textually enriched assessment tool that has the capacity to capture students' written explanations of their multiple-choice selections. The analysis of students' multiple-choice selections and written explanations will be used to provide automated scores and diagnostic reports, with indicators of students' conceptual understanding and likely causes of misconceptions, for both students and lecturers. We evaluate the pilot tool by analysing feedback regarding usability and comparing results of the computerized analysis of textual data, i.e. students' written explanations.

II. Tool Development

A. Signals and Systems concept inventory

The Signals and Systems CI is a 25-question multiple-choice exam developed to assess core concepts in undergraduate signals and systems courses. It was created and validated to reveal any student misconceptions by developing multiple-choice questions that assess certain concepts and includes distractors to identify the types of misconceptions students may have regarding that idea [4]. Our selection of this CI was due to the fact that we have repeatedly used it in our classes before, according to its authors' instructions. We enabled students to provide a textual response to capture their written explanations, to obtain the data needed to analyse the root causes of misconception rather than identifying only the symptoms of misconception.

B. Pilot Testing

The first administration of the concept inventory test augmented with the textual component was given to post graduate students in electrical engineering. This iteration revealed issues regarding usability and test fatigue. As a result, the online interface (used to capture multiple choice and textual responses) was redesigned to address these issues. The second iteration of testing utilized Google Forms. The test was also reduced to 15 questions, based on feedback from the first iteration's users who generally said they tired and tended to write less or not provide textual responses for the questions in the latter portion of the test.

Next, we piloted the textual concept inventory with undergraduate electrical engineering students. All students who took the exam were enrolled in a telecommunications course, and the test was administered in the first week of classes. Students who took the test also completed a course, in signals and transforms as a prerequisite, which covered the area of signals and linear systems.

Overall we received multiple-choice answers, textual responses explaining their selections, and feedback from 60 students. The 60 students submitted all responses electronically and completed the test within the allotted two-hour timeframe.

C. User Feedback

The researchers conducted a focus group interview with seven students who volunteered to participate in the interview. All students who took the textual concept inventory test were given the opportunity to participate and participant selection was limited to the students who volunteered. The interview questions were created to explore any issues that surfaced during the pilot testing, possible changes to the interface based on previous literature, and the general feedback students provided at the time of the online test administration.

One, 35-minute interview was conducted with the seven students and was structured to allow for more discussion with the participants, e.g. participants answered questions in an open format rather than each participant responding to individual questions. The interview was recorded and transcribed in order to perform a qualitative analysis of the student responses and feedback regarding their experience with the textual concept inventory.

Test mechanics was a reoccurring theme and covered the way the test was designed. Specifically, it included the pragmatics of the number of questions asked and time allowed to respond to them; the way the questions are structured and what kinds of responses required; and how the test may be constructed to contribute to student learning. The idea of including an opportunity for a plain free text response was well received. Students generally expressed that the text responses allow the textual concept inventory to become a test of understanding, rather than memory.

> *"I found it quite nice to be able to try and explain what you know. Which, like, instead of just having a pure multiple-choice where you're right or wrong, and those ones where you can go one way or the other. It's showing that you can't just guess correctly." (P5)*

> *"And that you can actually understand the content as well as what the answer is. You can look at it and go, 'I think it's that one. That looks right.' But why is it right? Triggers that brain process." (P7)*

One common sentiment students expressed was that the textual component gives insight into nuances of students' knowledge. The participants generally agreed that the textual component, or the opportunity to provide explanations or reasoning for the multiple-choice selection was beneficial to receiving credit for the correct knowledge expressed.

> *"It'd be great because you can sort of see who's just guessing their way through it. If you could explain enough to get to, I guess, half marks, and then the correct answer's the other half marks— or however you choose to weight it, that sort of assessment setting is nice." (P7)*

Another area the researchers considered was the capability for rich text entry, since the Signals and Systems CI is very visual in nature, e.g. questions are based on graphical representations. However, the students/ users did not feel a rich text option would not be useful.

> *"I think that [rich text entry] would just bore people." [All agree] (P1)*

> *"For a prior learning test, I think you would get less engagement doing that [including rich text entry] than you would as just a really short, like, basic thing. It would bore people and we'd end up with no feedback in that regard, because, personally, if it was for a prior learning test, I'd probably skip that part and just be inclined to check A, B, C, or D. That's just being honest." (P7)*

As the research team continues to evaluate the results and improve the tool, user feedback will be integrated into the design. The main aim of this type of tool is to use written explanations, i.e. text, to diagnose misconceptions, so changes to the design or structure will mainly be done to support that aim.

III. Textual Analysis

*A. **Automated Lexical Analysis**, Leximancer*

Previous studies in automated text analysis have shown machine learning methods more validly detect understanding than multiple-choice assessments and are capable of accurately capturing students' scientific ideas as accurately as human-scored explanations [5]. The automated analysis of students' written explanations developed through our project aims to ultimately provide lecturers with an assessment resource that requires no additional marking and can be administered to large class sizes.

For the initial analysis of textual data we utilized the software, Leximancer, to investigate the effectiveness of an automated analysis approach to revealing student misconceptions. Several aspects of Leximancer contributed to its selection for initial automated analysis. The important feature of Leximancer is the automatic processing. As opposed to NVivo and other qualitative and text analysis programs, it extracts concepts automatically. The automated extraction of concepts allows for better initial exploratory work, as opposed to other programs where you have to instruct it on what to find.

The multi-layered presentation allows for deeper analysis. For example, the themes are broad, concepts are narrower, and the possibility exists to drill down into a concept to get all the words that make up its 'thesaurus'. This allows the user to group ideas and draw on different levels of meaning. (Fig 1 presented in a following section) provides an example of the concept map presentation of concepts generated from the textual responses of some questions from the Signals and Systems CI.)

B. *Textual Responses*

We analyzed the textual responses from the sub-set of 15 questions of the Signals and Systems Concept Inventory using Leximancer. The questions were analyzed separately to address the specific concept(s) and possible misconceptions associated with each question/ item in the CI. We also examined correct and incorrect responses (correct and incorrect reflect the multiple choice answer selected by the students) separately to view differences in the structure of concepts and conceptual understanding.

As an example, one CI question presented students with a reference graphical representation of a signal at a certain frequency and amplitude. The MCQ options were graphical representations of signals varying in frequency and amplitude. The question was for students to select the correct representation of a higher frequency representation, as compared with the reference representation.

The concept maps generated by Leximancer, shown in Fig 1, illustrate the complexity (and lack of complexity) of conceptual relationships for text responses that accompanied correct and incorrect multiple-choice selections, respectively.

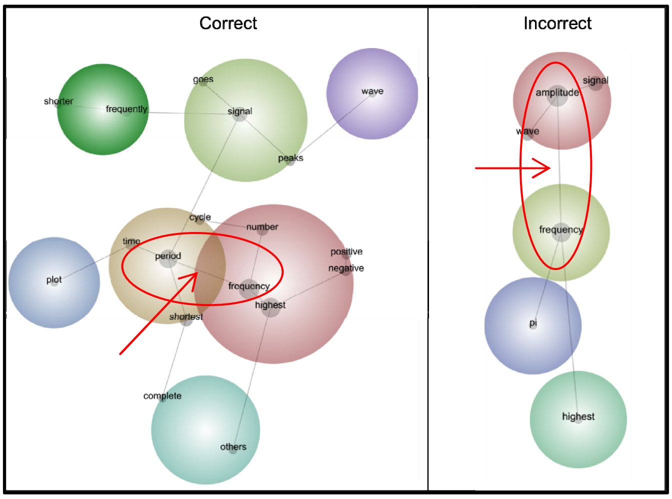

Fig. 1. Concept map of text responses.

Examples of the written, explanatory responses to each question (shown below) also demonstrate students' understanding and misconceptions related to frequency and period.

Responses to the correctly selected multiple-choice options:

- *"It has the shortest period and thus the highest frequency."*
- *"The frequency is how fast something takes to complete one wavelength. A) takes 10s. C) takes 10s D) takes 20s B) takes <2.5s"*
- *"During the same time, B has the most periods."*

A response to an incorrectly selected multiple-choice option:

- *"amplitude of the cos wave is the frequency, the largest amplitude is the largest frequency"*

These visualizations and automated analysis outputs are an important first step in creating the database or taxonomy of misconceptions. Information produced from the analysis will be used in creating and structuring the type of feedback provided to students and instructors in the diagnostic reports. The final student and instructor reports will not require additional interpretation from the visualizations, but this information will be used to form the suggested student studying strategies and instructor teaching strategies.

IV. Conclusions And Future Work

We aimed to employ textual analysis software to efficiently and, arguably, sustainably evaluate students' performance and deduce causes of conceptual misunderstanding, even for large textual response data sets, and presented results of our pilot data and analysis The results from the analysis of the textual data from pilot testing and user feedback revealed that the incorporation of text not only provides insight to students' conceptual understanding, but the proposed tool is also helpful to students in assessing and reflecting on their own understanding. Individual student responses reinforced the utility of the textual component to identify misconceptions through examples of correctly selected multiple-choice answers, but incorrect explanations.

The value of this approach as a formative assessment tool is due to its focus on assessment *for* learning (formatively), much more so than using assessment *of* learning (summatively). Properly designed, this type of assessment is more likely to enhance student learning by providing them and their teachers with evidence of their knowledge, understanding, and skills. The development of the validated tool can be applied at various stages of instruction to evaluate conceptual understanding to build on and improve student learning.

The implications from this study are important for creating and advancing an approach to engage students in higher-level thinking and reflexive thinking (through the use of written responses). Ultimately, we posit our approach to understanding and evaluating student misconception will contribute to building learning and (self-) assessment skills beyond the bounds of a course or program.

The main goal is to enhance students' conceptual understanding by developing a textual concept inventory approach that diagnoses the root causes of student misconceptions and thus facilitates focused teaching for enhanced learning outcomes. The addition of a text response field can also provide other pedagogical benefits. For example, studies have shown that eliciting student written responses to problems has also resulted in better conceptual understanding [6]. Future work will focus on analysing the textual data to gain further insights into the causes of conceptual misunderstanding.

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